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THE ORIGIN OF THE OLDEST FOSSILS AND THE DISCOVERY OF THE BOTTOM OF THE OCEAN.

IN the *Origin of Species* Darwin says that the sudden appearance of species belonging to several of the main divisions of the animal kingdom in the lowest known fossiliferous rocks, is at present inexplicable and may be truly urged as a valid objection to his views.

If his theory be true, he says that "it is indisputable that before the lowest Cambrian stratum was deposited long periods elapsed, as long as, or probably far longer than the whole interval from the Cambrian age to the present day; and that during these vast periods the world swarmed with living creatures. "Here," he says, "we encounter a formidable objection; for it seems doubtful whether the earth, in a fit state for the habitation of living creatures, has lasted long enough." "To the question why we do not find such fossiliferous deposits belonging to these assumed earliest periods prior to the Cambrian system I can give no satisfactory answer."

On its geological side this difficulty is even greater than it was in Darwin's day, for we now know that the fauna of the lower Cambrian was rich and varied; that most of the modern types of animal life were represented in the oldest fauna which has been discovered, and that all its types have modern representatives. The palæontological side of the subject has been ably summed up by Walcott in an interesting memoir on the oldest fauna which is known to us from fossils, and his collection

of 141 American species from the lower Cambrian is distributed over most of the marine groups of the animal kingdom, and except for the absence of the remains of vertebrated animals, the whole province of animal life is almost as completely covered by these 141 species as it could be by a collection from the bottom of the modern ocean. Four of the American species are sponges, two are hydrozoa, nine are actinozoa, twenty-nine are brachiopods, three are lamellibranchs, thirteen are gasteropods, fifteen are pteropods, eight are crustacea, fifty-one are trilobites, and trails and burrows show the existence of at least six species of bottom forms, probably worms or crustacea. The most notable characteristic of this fauna is the completeness with which these few species outline the whole fauna of the modern sea-floor. Far from showing us the simple unspecialized ancestors of modern animals, they are most intensely modern themselves in the zoölogical sense, and they belong to the same order of nature as that which prevails at the present day.

The fossiliferous beds of the lower Cambrian rest upon beds which are miles in vertical thickness, and are identical in all their physical features with those which contain this fauna. They prove beyond question that the waters in which they were laid down were as fit for supporting life at the beginning as at the end of the enormous lapse of time which they represent, and that all the conditions have since been equally favorable for the preservation and the discovery of fossils. Modern discovery has brought the difficulty which Darwin points out into clearer view, but geologists are no more prepared than he was to give a satisfactory solution, although I shall now try to show that the study of living animals in their relations to the world around them does help us, and that comparative anatomy and comparative embryology and the study of the habits and affinities of organisms tell us of times more ancient than the oldest fossils, and give a more perfect record of the early history of life than palæontology.

While the history of life, as told by fossils, has been slow and gradual it has not been uniform, for we have evidence of the

occurrence of several periods when modification was comparatively rapid.

We are living in a period of intellectual progress, and, among terrestrial animals, cunning now counts for more than size or strength, and fossils show that while the average size of mammals has diminished since the middle Tertiary, the size of their brains has increased more than one hundred per cent.; that the brain of a modern mammal is more than twice as large, compared with its body, as the brain of its ancestors in the middle Tertiary. Measured in years the middle Tertiary is very remote, but it is very modern compared with the whole history of the fossiliferous rocks, although more of brain development has been effected in this short time than in all preceding time from the beginning.

The later palæozoic and early secondary fossils mark another period of rapid change, when the fitness of the land for animal life, and the presence of land plants, brought about the evolution of terrestrial animals.

I shall give reasons for seeing, in the lower Cambrian, another period of rapid change, when a new factor, the discovery of the bottom of the ocean, began to act in the modification of species, and I shall try to show that, while animal life was abundant long before, the evolution of animals likely to be preserved as fossils took place with comparative rapidity, and that the zoölogical features of the lower Cambrian are of such a character as to indicate that it is a decided and unmistakable approximation to the primitive fauna of the bottom, beyond which life was represented only by minute and simple surface animals not likely to be preserved as fossils.

Nothing brings home more vividly to the zoölogist a picture of the diversity of the lower Cambrian fauna, and of its intimate relation to the fauna on the bottom of the modern ocean, than the thought that he would have found on the old Cambrian shore the same opportunity to study the embryology and anatomy of pteropods and gasteropods and lamellibranchs, of crustacea and medusæ, echinoderms and brachiopods that he now has at a

marine laboratory; that his studies would have followed the same lines then that they do now, and that most of the record of the past which they make known to him would have been ancient history then. Most of the great types of ancient life show by their embryology that they run back to simple and minute ancestors which lived at the surface of the ocean, and that the common meeting point must be projected back to a still more remote time, before these ancestors had become differential from each other.

After we have traced each great line of modern animals as far backwards as we can through the study of fossils, we still find these lines distinctly laid down. The lower Cambrian crustacea, for example, are as distinct from the lower Cambrian echinoderms or pteropods or lamellibranchs or brachiopods as they are from these of the present day, but zoölogy gives us evidence that the early steps in the establishment of these great lines were taken under conditions which were essentially different from those which have prevailed, without any essential change from the time of the oldest fossils to the present day, and that most of the great lines of descent were represented in the remote past by ancestors which, living a different sort of life, differed essentially, in structure as well as in habits, from the representatives of the same types which are known to us as fossils.

In the echinoderms we have a well defined type represented by abundant fossils, very rich in living forms, very diversified in its modification and therefore well fitted for use as an illustration. This great stem contains many classes and orders, all constructed on the same plan, which is sharply isolated and quite unlike the plan of structure in any other group of animals. All through the series of fossiliferous rocks echinoderms are found, and their plan of structure is always the same. Palæontology gives us most valuable evidence regarding the course of evolution within the limits of a class, as in the crinoids or the echinoids; but we appeal to it in vain for light upon the organization of the primitive echinoderm, or for connecting links between the classes. To our questions on these subjects, and on the relation of the

echinoderms to other animals, palæontology is silent, and throws them back upon us as unsolved riddles.

The zoölogist unhesitatingly projects his imagination, held in check only by the laws of scientific thought, into the dark period before the times of the oldest fossils, and he feels absolutely certain of the past existence of a stem, from which the classes of echinoderms have inherited the fundamental plan of their structure. He affirms with equal confidence that the structural changes which have separated this ancient type from the classes which we know from fossils, are very much more profound and extensive than all the changes which each class has undergone from the earliest palæozoic times to the present day.

He is also disposed to assume, but, as I shall show, with much less reason, that the amount of change which structure has undergone is an index to the length of time which the change has required, and that the period which is covered by the fossiliferous rocks is only an inconsiderable part of that which has been consumed in the evolution of the echinoderms.

The zoölogist does not check the flight of his scientific imagination here, however, for he trusts implicitly to the embryological evidence which teaches him that, still farther back in the past, all echinoderms were represented by a minute floating animal which was not an echinoderm at all in any sense except the ancestral one, although it was distinguished by features which natural selection has converted, under the influence of modern conditions, into the structure of echinoderms. He finds in the embryology of modern echinoderms phenomena which can bear no interpretation but this, and he unhesitatingly assumes that they are an inheritance which has been handed down from generation to generation through all the ages from the prehistoric times of zoölogy.

Other groups tell the same story with equal clearness. A lingula is still living in the sand bars and mud flats of the Chesapeake Bay, under conditions which have not effected any essential change in its structure since the time of the lower Cambrian. Who can look at a living lingula without being

overwhelmed by the effort to grasp its immeasurable antiquity; by the thought that while it has passed through all the chances and changes of geological history, the structure which fitted it for life on the earliest palæozoic bottom is still adapted for a life on the sands of the modern sea floor?

The everlasting hills are the type of venerable antiquity; but lingula has seen the continents grow up, and has maintained its integrity unmoved by the convulsions which have given the crust of the earth its present form.

As measured by the time-standards of the zoölogist lingula itself is modern, for its life-history still holds locked up in its embryology the record, repeated in the development of each individual, of a structure and a habit of life which were lost in the unknown past at the time of the lower Cambrian, and it tells us vaguely but unmistakably of life at the surface of the primitive ocean, at a time when it was represented by minute and simple floating ancestors.

Broadly stated, the history of each great line has been like that of the echinoderms and brachiopods. The oldest pteropod or lamellibranch or echinoderm or crustacean or vertebrate which we know from fossils exhibits its own type of structure with perfect distinctness, and later influences have done no more than to expand and diversify the type, while anatomy fails to guide us back to the point where these various lines met each other in a common source, although it forces us to believe that the common source once had an individual existence. Embryology teaches that each line once had its own representative at the surface of the ocean, and that the early stages in its evolution have passed away and left no record in the rocks.

If we try to call before the mind a picture of the land surface of the earth we see a vast expanse of verdure, stretching from high up in the mountains over hills, valleys, and plains, and through forests and meadows down to the sea, with only an occasional lake or broad river to break its uniformity.

Our picture of the ocean is an empty waste, stretching on and on with no break in the monotony except now and then a

flying fish or a wandering sea bird or a floating tuft of sargassum, and we never think of the ocean as the home of vegetable life. It contains plant-like animals in abundance, but these are true animals and not plants, although they are so like them in form and color. At Nassau, in the Bahama Islands, the visitor is taken in a small boat, with windows of plate-glass set in the bottom, to visit the "sea-gardens" at the inner end of a channel through which the pure water from the open sea flows between two coral islands into the lagoon. Here the true reef-corals grow in quiet water, where they may be visited and examined.

When illuminated by the vertical sun of the tropics and by the light which is reflected back from the white bottom, the pure transparent water is as clear as air, and the smallest object forty or fifty feet down is distinctly visible through the glass bottom of the boat.

As this glides over the great mushroom-shaped coral domes which arch up from the depths, the dark grottoes between them and the caves under their overhanging tops are lighted up by the sun, far down among the anthozoa or flower animals and the zoöphytes or animal plants, which are seen through the waving thicket of brown and purple sea fans and sea feathers as they toss before the swell from the open ocean.

There are miles of these "sea gardens" in the lagoons of the Bahamas, and it has been my good fortune to spend many months studying their wonders, but no description can convey any conception of their beauty and luxuriance.

The general effect is very garden-like, and the beautiful fishes of black and golden yellow and iridescent cobalt blue hover like birds among the thickets of yellow and lilac gorgonias.

The parrot fishes seem to be cropping the plants like rabbits, but more careful examination shows that they are biting off the tips of the gorgonias and branching madrepores or hunting for the small crustacea which hide in the thicket and that all the apparent plants are really animals.

The delicate star-like flowers are the vermillion heads of

boring annelids or the scarlet tentacles of actinias, and the thicket is made up of pale lavender bushes of branching madrepores, and green and brown and yellow and olive masses of brain coral, of alcyonarians of all shades of yellow and purple, lilac and red, and of black and brown and red sponges. Even the lichens which incrust the rocks are hydroid corals, and the whole sea garden is a dense jungle of animals, where plant-life is represented only by a few calcareous algæ so strange in shape and texture that they are much less plant-like than the true animals.

The scarcity of plant-life becomes still more notable when we study the ocean as a whole. On land herbivorous animals are always much more abundant and prolific than the carnivora, as they must be to keep up the supply of food, but the animal life of the ocean shows a most remarkable difference, for marine animals are almost exclusively carnivorous.

The birds of the ocean, the terns, gulls, petrels, divers, cormorants, tropic birds and albatrosses, are very numerous indeed, and the only parallel to the pigeon roosts and rookeries of the land is found in the dense clouds of sea birds around their breeding grounds, but all these sea birds are carnivorous, and even the birds of the seashore subsist almost exclusively upon animals such as mollusca, crustacea and annelids.

The seals pursue and destroy fishes; the sea-elephants and walruses live upon molluscs; the whales, dolphins and porpoises and the marine reptiles all feed upon animals and most of them are fierce beasts of prey.

There are a few fishes which pasture in the fringe of seaweed which grows on the shore of the ocean, and there are some which browse among the floating tufts of algæ upon its surface, but most of them frequent these places in search of the small animals which hide among the plants.

In the Chesapeake Bay the sheepshead browses among the algæ upon the submerged rocks and piles like a marine sheep, but its food is exclusively animal, and I have lain upon the edge of a wharf watching it crunch the barnacles and young oysters until the juices of their bodies streamed out of the angles of

its mouth and gathered a host of small fishes to snatch the fragments as they drifted away with the tide.

Many important fishes, like the cod, pasture on the bottom, but their pasturage consists of molluscs and annelids and crustacea instead of plants, and the vast majority of sea fishes are fierce hunters, pursuing and destroying smaller fishes, and often exhibiting an insatiable love of slaughter, like our own blue fish and tropical albacore and barracuda. Others, such as the herring, feed upon smaller fishes and the pelagic pteropods and copepods; and others, like the shad, upon the minute organisms of the ocean, but all, with few exceptions, are carnivorous. In the other great groups of marine animals we find some scavengers, some which feed upon micro-organisms, and others which hunt and destroy each other, but there is no group of marine animals which corresponds to the herbivora and rodents and the plant-eating birds and insects of the land.

There is so much room in the vast spaces of the ocean, and so much of it is hidden, that it is only when surface animals are gathered together that the abundance of marine life becomes visible and impressive; but some faint conception of the boundless wealth of the ocean may be gained by observing the quickness with which marine animals become crowded together at the surface in favorable weather. On a cruise of more than two weeks along the edge of the gulf stream, I was surrounded continually night and day by a vast army of dark brown jelly-fish, (Linerges mercutia) whose dark color made them very conspicuous in the clear water. We could see them at a distance from the vessel, and at noon when the sun was over head we could look down to a great depth through the centre-board well, and everywhere, to a depth of fifty or sixty feet, we could see them drifting by in a steady procession, like motes in a sunbeam. We cruised through them for more than five hundred miles and we tacked back and forth over a breadth of almost a hundred miles, and found them everywhere in such abundance that there were some in every bucketful of water which we dipped up, nor is this abundance of life restricted to tropical waters, for Haeckel tells us

that he met with such enormous masses of Limacina to the northwest of Scotland, that each bucket of water contained thousands.

The tendency to gather in crowds is not restricted to the smaller animals, and many species of raptorial fishes are found in densely packed banks.

The fishes in a school of mackerel are as numerous as the birds in a flight of wild pigeons, and we are told of one school which was a windrow of fish half a mile wide and at least twenty miles long. But while pigeons are plant eaters, the mackerel are rapacious hunters, pursuing and devouring the herrings as well as other animals.

Herring swarm like locusts, and a herring bank is almost a solid wall. In 1879 three hundred thousand river herring were landed in a single haul of the seine in Albemarle Sound; but the herring are also carnivorous, each one consuming myriads of copepods every day.

In spite of this destruction and the ravages of armies of medusae and siphonophores and pteropods the fertility of the copepods is so great that they are abundant in all parts of the ocean, and they are met with in numbers which exceed our power of comprehension. On one occasion the "Challenger" steamed for two days through a dense cloud formed of a single species, and they are found in all latitudes from the arctic regions to the equator in masses which discolor the water for miles. We know, too, that they are not restricted to the surface, and that the banks of copepods are sometimes more than a mile thick. When we reflect that thousands would find ample room and food in a pint of water, one can form some faint conception of their universal abundance.

The organisms which are visible in the water of the ocean and on the sea bottom are almost universally engaged in devouring each other, and many of them, like the blue-fish, are never satisfied with slaughter, but kill for mere sport.

Insatiable rapacity must end in extermination unless there is some unfailing supply, and as we find no visible supply in the

water of the ocean we must seek it with a microscope, which shows us a wonderful fauna made up of innumerable larvæ and embryos and small animals, but these things cannot be the food-supply of the ocean, for no carnivorous animal could subsist very long by devouring its own children. The total amount of these animals is inconsiderable, however, when compared with the abundance of a few forms of protozoa and protophytes, and both observation and deduction teach that the most important element in marine life consists of some half-dozen types of protozoa and unicellular plants: of globigerina and radiolarians, and of trichodesmium, pyrocystis, protococcus and the coccospheres rhabdospheres and diatoms.

Modern microscopic research has shown that these simple plants, and the globigerinæ and radiolarians which feed upon them, are so abundant and prolific that they meet all demands and supply the food for all the animals of the ocean.

This is the fundamental conception of marine biology. The basis of all the life in the modern ocean is found in the micro-organisms of the surface.

This is not all. The simplicity and abundance of the microscopic forms and their importance in the economy of nature show that the organic world has gradually taken shape around them as its centre or starting-point, and has been controlled by them.

They are not only the fundamental food-supply but the primeval supply, which has determined the whole course of the evolution of marine life.

The pelagic plant-life of the ocean has retained its primitive simplicity on account of the very favorable character of its environment, and the higher rank of the littoral vegetation and that of the land is the result of hardship.

On land the mineral elements of plant-food are slowly supplied, as the rains dissolve them; limited space brings crowding and competition for this scanty supply; growth is arrested for a great part of each year by drought or cold; the diversity of the earth's surface demands diversity of structure and habit, and

the great size and complicated structure of terrestrial plants are adaptations to these conditions of hardship.

At the surface of the ocean the abundance and uniform distribution of mineral food in solution; the area which is available for plants; the volume of sunlight and the uniformity of the temperature are all favorable to the growth of plants, and as each plant is bathed on all sides by a nutritive fluid, it is advantageous for the new plant-cells which are formed by cell-multiplication, to separate from each other as soon as possible, in order to expose the whole of their surface to the water. Cell-aggregation, the first step towards higher organization, is therefore disadvantageous to the pelagic plants, and as the environment at the surface of the ocean is so monotonous, there is little opportunity for an aggregation of cells to gain any compensating advantage by seizing upon a more favorable habitat. The pelagic plants have retained their primitive simplicity, and the most distinctive peculiarity of the microscopic food-supply of the ocean is the very small number of forms which make up the enormous mass of individuals.

All the animals of the ocean are dependent upon this supply of microscopic food, and many of them are adapted for preying upon it directly, but a review of the animal kingdom will show that no highly organized animal has ever been evolved at the surface of the ocean although all depend upon the food-supply of the surface.

The animals which now find their home in the open waters of the ocean are, almost without exception, descendants of forms which lived upon or near the bottom, or along the sea-shore, or upon the land, and all the exceptions are simple animals of minute size. A review of the whole animal kingdom would take more space than we can spare, but it would show that the evidence from embryology, from comparative anatomy and from palæontology, all bears in the same direction and proves that every large and highly organized animal in the open ocean is descended from ancestors whose home was not open water but solid ground, either on the bottom or on the shore.

Embryology also gives us good ground for believing that all these animals are still more remotely descended from minute and simple pelagic ancestors, and that the history of all the highly organized inhabitants of the water has followed a roundabout path from the surface to the bottom and then back into the water.

When this fact is seen in all its bearings and its full significance is grasped, it is certainly one of the most notable and instructive features of evolution.

The food-supply of marine animals consists of a few species of microscopic organisms which are inexhaustible and the only source of food for all the inhabitants of the ocean. The supply is primeval as well as inexhaustible, and all the life of the ocean has gradually taken shape in direct dependence upon it.

In view of these facts we cannot but be profoundly impressed by the thought that all the highly organized marine animals are products of the bottom or the shore or the land, and that while the largest animals on earth are pelagic the few which are primitively pelagic are small and simple.

The reason is obvious. The conditions of life at the surface are so easy that there is little fierce competition, and the inorganic environment is so simple that there is little chance for diversity of habits.

The growth of terrestrial plants is limited by the scarcity of food, but there is no such limit to the growth of pelagic plants or the animals which feed on them, and while the balance of life is no doubt adjusted by competition for food this is never very fierce, even at the present day, when the ocean swarms with highly organized wanderers from the bottom and the shore. Even now the destruction or escape of a microscopic pelagic organism depends upon the accidental proximity or remoteness of an enemy rather than upon defense or protection, and survival is determined by space relations rather than a struggle for existence.

The abundance of food is shown by the ease with which wanderers from the land, like sea birds, find places for them-

selves in the ocean, and the rapidity with which they spread over its whole extent.

As a marine animal the insect, Halobates, must be very modern as compared with most pelagic forms, yet it has spread over all tropical and sub-tropical seas, and it may always be found skimming over the surface of mid-ocean as much at home as a Gerris in a pond. I never found it absent in the Gulf Stream when conditions were favorable for collecting.

The easy character of pelagic life is shown by the fact that the larvæ of innumerable animals from the bottom and the shore have retained their pelagic habit, and I shall soon give reasons for believing that the larva of a shore animal is safer at sea than near the shore.

There was little opportunity in the primitive pelagic fauna and flora for an organism to gain superiority by seizing upon an advantageous site or by acquiring peculiar habits, for one place was like another, and peculiar habits could count for little in comparison with accidental space relations. After the fauna of the surface had been enriched by all the marine animals which have become secondarily adapted to pelagic life, competition with those improved forms brought about improvements in those which were strictly pelagic in origin, like the siphonophores, and those wanderers from the bottom introduced another factor into the evolution of pelagic life, for their bodies have been utilized for protection or concealment and in other ways, and we now have fishes which hide in the poison curtain of Physalia, crustacea which live in the pharynx of Salpa or in the mouth of the manhaden, barnacles and sucking fish fastened to whales and turtles, besides a host of external and internal parasites. The primitive ocean furnished no such opportunity, and the conditions of pelagic life must at first have been very simple, and while competition was not entirely absent the possibilities of evolution must have been extremely limited and the progress of divergent modification very slow so long as all life was restricted to the waters of the ocean.

There can be no doubt that floating life was abundant for a

long period when the bottom was uninhabited. The slow geological changes by which the earth gradually assumed its present character present a boundless field for speculation, but there can be no doubt that the surface of the primeval ocean became fit for living things long before the deeper waters or the sea floor, and during this period the proper conditions for the production of large and complicated organisms did not exist, and even after the total amount of life had become very great it must have consisted of organisms of small size and simple structure.

Marine life is older than terrestrial life, and as all marine life has shaped itself in relation to the pelagic food supply, this itself is the only form of life which is independent, and it must therefore be the oldest. There must have been a long period in primeval times when there was a pelagic fauna and flora rich beyond limit in individuals, but made up of only a few simple types. During this time the pelagic ancestors of all the great groups of animals were slowly evolved, as well as other forms which have left no descendants. So long as life was restricted to the surface no great or rapid advancement, through the influences which now modify species, was possible, and we know of no other influences which might have replaced them. We are, therefore, forced to believe that the differentiation and improvement of the primitive flora and fauna was slow, and that, for a vast period of time, life consisted of an innumerable multitude of minute and simple pelagic organisms. During the time which it took to form the thick beds of older sedimentary rocks, the physical conditions of the ocean gradually took their present form, and during a part at least of this period the total amount of life in the ocean may have been very nearly as great as it is now without leaving any permanent record of its existence, for no rapid advance took place until the advantages of life on the bottom were discovered.

We must not think of the populating of the bottom as a physical problem, but as discovery and colonization, very much like the colonization of islands. Physical conditions for a long time made it impossible, but its initiation was the result of bio-

logical influences, and there is no reason why its starting point should necessarily be the point where the physical obstacles first disappeared. It is useless to speculate upon the nature of the physical obstacles; there is reason to think one of them, probably an important one, was the deficiency of oxygen in deep water.

Whatever their character may have been they were all, no doubt, of such a nature that they first disappeared in the shallow water around the coast, but it is not probable that bottom life was first established in shallow water, or before the physical conditions had become favorable at considerable depths.

The sediment near the shore is destructive to most surface animals, and recent explorations have shown that a stratum of water of very great thickness is necessary for the complete development of the floating microscopic fauna and flora, and it is a mistake to picture them as confined to a thin surface stratum. Pelagic plants probably flourished as far down as light penetrates, and pelagic animals are abundant at very great depths. As the earliest bottom animals must have depended directly upon the floating organisms for food, it is not probable that they first established themselves in shallow water, where the food supply is both scanty and mixed with sediment; nor is it probable that their establishment was delayed until the great depths had become favorable to life.

The belts around elevated areas far enough from shore to be free from sediment, and deep enough to permit the pelagic fauna to reach its full development above them, are the most favorable spots, and palæontological evidence shows that they were seized upon very early in the history of life on the bottom.

It is probable that colony after colony was established on the bottom and afterwards swept away by geological change like a cloud before the wind, and that the bottom fauna, which we know was not the first. Colonies which started in shallow water, were exposed to accidents from which those in great depths were free; and in view of our knowledge of the permanency of the sea-floor and of the broad outlines of the continents, it is not impossible that the first fauna which became established in the deep zone

around the continents may have persisted and given rise to modern animals. However this may be, we must regard this deep zone as the birthplace of the fauna which has survived; as the ancestral home of all the improved metazoa.

The effect of life upon the bottom is more interesting than the place where it began, and we are now to consider its influence upon animals, all whose ancestors and competitors and enemies had previously been pelagic. The cold, dark, silent, quiet depths of the sea are monotonous compared with the land, but they introduced many new factors into the course of organic evolution.

It is doubtful whether the animals which first settled on the bottom secured any more food than floating ones, but they undoubtedly obtained it with less effort, and were able to devote their superfluous energy to growth and to multiplication, and thus to become larger and to increase in numbers faster than pelagic animals. Their sedentary life must have been favorable to both sexual and asexual multiplication, and the tendency to increase by budding must have been quickly rendered more active, and one of the first results of life on the bottom must have been to promote the tendency to form connected cormi, and to retain the connection between the parent and the bud until the latter was able to obtain its own food and to care for itself. The animals which first acquired the habit of resting on the bottom soon began to multiply faster than their swimming allies, and their asexually produced progeny, remaining for a longer time attached to and nourished by the parent stock, were much more favorably placed for rapid growth. As the animals of the bottom live on a surface, or at least a thin stratum, while swimming animals are distributed through solid space, the rapid multiplication of bottom animals must soon have led to crowding and to competition, and it quickly became harder and harder for new forms from the open water to force themselves in among the old ones, and colonization soon came to an end.

The great antiquity of all the types of structure which are represented among modern animals is therefore what we should

expect, for after the foundation of the fauna of the bottom was laid it became, and has ever since remained, difficult for new forms to establish themselves.

Most of our knowledge of the sea bottom is from three sources: from dredgings and other explorations; from rocks which were formed beyond the immediate influence of continents, and from the patches of the bottom fauna which have gradually been brought near its surface by the growth of coral reefs, and from all these sources we have testimony to the density of the crowd of animals on favorable spots. Deep sea explorations give only the most scanty basis for a picture of the sea bottom, but they show that animal life may thrive with the dense luxuriance of tropical vegetation, and Sir Wyville Thomson says he once brought up at one time on a tangle which was fastened to a dredge over twenty thousand specimens of a single species of sea urchin. The number of remains of palæozoic crinoids and brachiopods and trilobites which are crowded into a single slab of fine grained limestone is most astounding, and it testifies most vividly and forcibly to the wealth of life on the old sea-floor.

No description can convey any adequate conception of the boundless luxuriance of a coral island, but nothing else gives such a vivid picture of the capacity of the sea-floor for supporting life. Marine plants are not abundant on coral islands and the animals depend either directly or indirectly upon the pelagic food-supply, so that their life is the same in this respect as that of animals in the deep sea far from land.

The abundant life is not restricted to the growing edge of the reef, and the inner lagoons are often like crowded aquaria. At Nassau my party of eight persons found so much to study on a little reef in a lagoon close to our laboratory that we discovered novelties every day for four months and our explorations seldom carried us beyond this little tract of bottom. Every inch of the bottom was carpeted with living animals, while others were darting about among the corals and gorgonias in all directions; but this was not all, for the solid rock was honeycombed every-

where by tubes and burrows, and when broken to pieces with a hammer each mass of coral gave us specimens of nearly every great group in the animal kingdom. Fishes, crustacea, annelids, mollusca, echinoderms, hydroids and sponges could be picked out of the fragments and the abundance of life inside the solid rock was most wonderful.

The absence of pelagic life in the landlocked water of coral islands is as impressive and noteworthy as the luxuriance of life upon and near the bottom.

On my first visit to the Bahama Islands I was sadly disappointed by the absence of pelagic animals where all the conditions seemed to be peculiarly favorable.

The deep ocean is so near that, as one cruises through the inner sounds past the openings between the islets which form the outer barrier, the deep blue water of mid-ocean is seen to meet the white sand of the beach, and soundings show that the outer edge is a precipice as high as the side of Chimborazo and much steeper.

Nowhere else in the world is the pure water of the deep sea found nearer land or more free from sediment, and on the days when the weather was favorable for outside collecting we found siphonophores and pteropods, pelagic molluscs and crustacea and tunicates and all sorts of pelagic larvæ in great abundance in the open water just outside the inlets.

Inside the barrier the water was always calm, and day after day it was as smooth as the surface of an inland lake. When I first entered one of these beautiful sounds, where the calm transparent water stretches as far as the eye can reach, while new beauties of islets and winding channels open before one as those which are passed fade away on the horizon, I felt sure that I had at last found a place where the pelagic fauna of mid-ocean could be gathered at our door and studied on shore. The water proved to be not only as pure as air but almost as empty. At high water we sometimes captured a few pelagic animals near the inlets, but we dragged our surface nets through the sounds day after day only to find them as clean as if they had been

hung in the wind to dry. The water in which we washed them usually remained as pure and empty as if it had been filtered, and we often returned from our touring expeditions without even a copepod or a zoea or a pluteus.

The absence of the floating larvæ is most remarkable, for the sounds swarm with bottom animals which give birth every day to millions of swimming larvæ. The mangrove swamps and the rocky shores are fairly alive with crabs carrying eggs at all stages of development, and the boat passes over great black patches of sea-urchins crowded together by thousands. The number of animals engaged in laying their eggs or hatching their young is infinite, yet we rarely captured any larvæ in the tow net, and most of these we did find were well advanced and nearly through their larval life.

It is often said that the water of coral sounds is too full of lime to be inhabited by the animals of the open ocean, but this is a mistake, for the water is perfectly fit for supporting the most delicate and sensitive animals, and those which we caught outside lived in the house in water from the sounds better than in any other place where I ever tried to keep them, and instead of being injurious, the pure water of coral sounds is peculiarly favorable for use in aquaria for surface animals.

The scarcity of floating organisms can have only one explanation. They are eaten up, and competition for food is so fierce that nearly every organism which is swept in by the tide and nearly every larva which is born in the sounds is snatched by the tentacles around some hungry mouth.

Nothing could illustrate the fierceness of the struggle for food among the animals on a crowded sea-bottom more vividly than the emptiness of the water in coral sounds where the bottom is practically one enormous mouth. The only larvæ which have much chance to establish themselves for life are those which are so fortunate as to be swept out into the open ocean where they can complete their larval life under the milder competition of the pelagic fauna, and while it is usually stated that the larvæ of bottom animals have retained the pelagic habit for the purpose

of distributing the species, it is more probable that it has been retained on account of its comparative safety.

These facts show that competition must have come quickly after the establishment of the first fauna on the bottom, and that it soon became very rigorous and led to severe selection and rapid modification; and we must also remember that life on the bottom brought with it many new opportunities for divergent specialization and improvement. The increase in size which came with economy of energy increased the possibilities of variation and led to the natural selection of peculiarities which improved the efficacy of the various parts of the body in their functions of relation to each other, and this has been an important factor in the evolution of complicated organisms.

The new mode of life also permitted the acquisition of protective shells, hard-supporting skeletons and other imperishable parts, and it is therefore probable that the history of evolution in later times gives no index as to the period which was required to evolve from small, simple pelagic ancestors the oldest animals which were likely to be preserved as fossils.

Life on the bottom also introduced another important evolutionary influence: competition between blood-relations. In those animals, which we know most intimately, divergent modification, with the extinction of connecting forms, results from the fact that the fiercest competitors of each animal are its closest allies, which, having the same habits, living upon the same food, and avoiding enemies in the same way, are constantly striving to hold exclusive possession of all that is essential to their welfare.

When a stock gives rise to two divergent branches, each escapes competition with the other so far as they differ in structure or habits, while the parent stock competing with both at a disadvantage is exterminated.

Among the animals which we know best, evolution leads to a branching tree-like genealogy with the topmost twigs represented by living animals while the rest of the tree is buried in the dead past. The connecting form between two species must therefore

be sought in the records of the past or reconstructed by comparison.

Even at the present day things are somewhat different in the open ocean, and they must have been very different in the primitive ocean, for a pelagic animal has no fixed home, one locality is like another, and the competitors and enemies of each individual are determined in great part by accidents.

We accordingly find, even now, that the evolution of pelagic animals is often linear instead of divergent, and ancient forms, such as the sharks, often live on side by side with the later and more evolved forms. The radiolarians and medusæ and siphonophores furnish many well-known illustrations of this feature of pelagic life.

No naturalist is surprised to find in the South Pacific or in the Indian Ocean a salpa or a pelagic crustacean or a surface fish or a whale which was previously known only from the North Atlantic, and the list of species of marine animals which are found in all seas is a very long one. The fact that pelagic animals are so independent of those laws of geographical distribution which limit land animals is additional evidence of the easy character of the conditions of pelagic life.

One of the first results of life on the bottom was to increase asexual multiplication and to lengthen the time during which buds remain united to and nourished by their parents, and to crowd individuals of the same species together and to cause competition between relations. We have in this and other obvious peculiarities of life on the bottom a sufficient explanation of the fact that since the first establishment of the bottom fauna, evolution has resulted in the elaboration and divergent specialization of the types of structure which were already established rather than the production of new types.

Another result of the struggle for existence on the bottom was the escape of varieties from competition with their allies by flight from the crowded spots and a return to the open water above; just as in later times the whales and sea birds have gone back from the land to the ocean.

These emigrants, like the civilized men who invade the homes of peaceful islanders, brought with them the improvements which had come from fierce competition, and they have carried everything before them and produced a great change in the pelagic fauna.

The rapid intellectual development which has taken place among the mammals since the middle Tertiary, and the rapid structural changes which took place in animals and plants when the land fauna and flora were established, are well known, but the fact that the discovery of the bottom initiated a much earlier and probably more important era of rapid development in the forms of animal life has never been pointed out.

If this view is correct the primitive fauna of the bottom must have had the following characteristics: 1. It was entirely animal, without plants, and it at first depended directly upon the pelagic food supply.

2. It was established around elevated areas in water deep enough to be beyond the influence of the shore.

3. The great groups of animals were rapidly established from pelagic ancestors.

4. The animals of the bottom rapidly increased in size and hard parts were quickly acquired.

5. The bottom fauna soon produced progressive development among pelagic animals.

6. After the establishment of the fauna of the bottom elaboration and differentiation among the representatives of each primitive type soon set in and led to the extinction of connecting forms.

Many of the oldest fossils like the pteropods are the modified descendants of ancestors with hard parts, and there is no reason to suppose that the first animals which were capable of preservation as fossils have been discovered, but it is interesting to note that the oldest known fauna is an unmistakable approximation to the primitive fauna of the bottom.

The lower Cambrian fossils are distributed through strata more than two miles thick, some, at least, of them showing by

their fine grain and by the perfect preservation of tracks and burrows which were made in soft mud, and of soft animals like jelly fish, that they were deposited in water of considerable depth. The sediment was laid down slowly and gently in water so deep as to be free from disturbance aud under conditions so favorable that it contains the remains of delicate animals not often found as fossils.

While the fauna of the lower Cambrian undoubtedly lived in water of very considerable depth it was not oceanic but continental, for we are told by Walcott that "one of the most important conclusions is that the fauna of the lower Cambrian lived on the eastern and western shores of a continent that in its general configuration outlines the American continent of to-day." "Strictly speaking the fauna did not live upon the outer shore facing the ocean, but on the shores of interior seas, straits or lagoons that occupied the intervals between the several ridges that ran from the central platform east and west of the main continental land surface of the time."

This fauna was rich and varied, but it was not self-supporting, for no fossil plants are found, and the primary food supply was pelagic. Animals adapted for a rapacious life, such as the pteropods, were abundant, and prove the existence of a rich supply of pelagic animals. All the forms known from the fossils are either carnivorous, like the medusae, corals, crustacea, and trilobites, or they are adapted, like the sponges, brachiopods, and lamellibranchs, for straining minute organisms out of the water or for gathering those which rained down from above, and the conditions under which they lived were very similar to those on the bottom at the present day.

Walcott's studies show that the earliest known fauna had the following characteristics: It consisted, so far as the record shows, of animals alone, and these were dependent upon the pelagic food supply for support. While small in comparison with many modern animals, they were gigantic compared with primitive pelagic animals. The species were few, but they represent a very wide range of types. All these types have mod-

ern representatives, and most of the modern types are represented in the lower Cambrian. Their home was not the bottom of the deep ocean, but the shores of a continent under water of considerable depth.

The Cambrian fauna is usually regarded as a half-way station in a series of animal forms which stretches backwards into the past for an immeasurable period, and it is even stated that the history of life before the Cambrian is larger by many fold than its history since.

So far as this opinion rests on the diversity of types in Cambrian times, it has no good basis; for if the views here advocated are correct the evolution of the ancestral stems took place at the surface, and all the conditions necessary for the rapid production of types were present when the bottom fauna first became established.

As we pass backwards towards the lower Cambrian we find closer and closer agreement with the zoölogical conception of the character of primitive life on the bottom. While we cannot regard the oldest fauna which has been discovered as the first which existed on the bottom, we may feel confident that the first fauna of the bottom resembled that of the lower Cambrian in its physical conditions and in its most distinctive peculiarities; the abundance of types, and the slight amount of differentiation among the representatives of these types; and we must regard it as a decided and unmistakable approximation to the beginning of the modern fauna of the earth, as distinguished from the more ancient and simple fauna of the open ocean.

W. K. BROOKS.

Professor of Zoölogy in the Johns Hopkins University.